**AS Unit BY2: Biodiversity and Physiology of Body Systems**

| Name: | Date: |
|---|---|

**Topic 2.3 Transport (Plants)** – Page 1A

(d) Structure of the dicotyledon root. Absorption of water. Movement of water through the root: apoplast, symplast and vacuolar pathways. Structure and role of endodermis. The structure of xylem. Movement of water from root to leaf. Transpiration stream, cohesion-tension theory. Environmental factors affecting transpiration. Angiosperm adaptations: hydrophytes, xerophytes

(e) The structure of phloem as seen by the light and electron microscope. Translocation of organic materials from source to sink. Phloem transport: diffusion; cytoplasmic strands; mass flow models. Experimental evidence that solutes e.g. sucrose, are carried in the phloem. Use of aphids and autoradiographs. *

Suggested Practical Activities: Examination of TS primary stem dicotyledon and root.TS and LS primary xylem and phloem. The use of a simple potometer. Computer modelling may be used to extend this investigation. TS leaf marram grass and water lily. Examination of epidermal strips and/or replicas to compare stomatal numbers in leaves adapted to different environments. Examination of TS artery and vein. Observation of erythrocytes and leucocytes in prepared blood smears.

Prior to AS level you probably only looked at the functions of xylem and phloem. In unit 2.1 you should also draw in your knowledge of the cohesive, adhesive and transport properties of water.

| | | Completed |
|---|---|---|
| 1. | Structure of Dicotyledonous Roots and the Transport of water and nitrogen into the plant.<br>• What are the tissues found in roots and how are they distributed?<br>• How does water enter the root and travel to the xylem vessels?<br>• What is the Casparian strip? | |
| 2. | Read page 4-6 Transport of water into and across the roots<br>Complete tasks on the pages. | |
| 3. | Read page 7-8 Structure of Stems<br>Complete the questions and tasks on pages 7-8 | |
| 4. | Read pages 9-11 Passage of Water up the Plant – Transpiration<br>Complete all questions | |
| 6. | Read pages 12-14 on Mesophytes, hydrophytes and xerophytes and answer the questions. | |
| 7. | Explain why transpiration in plants is:<br>i. inevitable<br>ii. desirable<br>iii. Undersirable | |

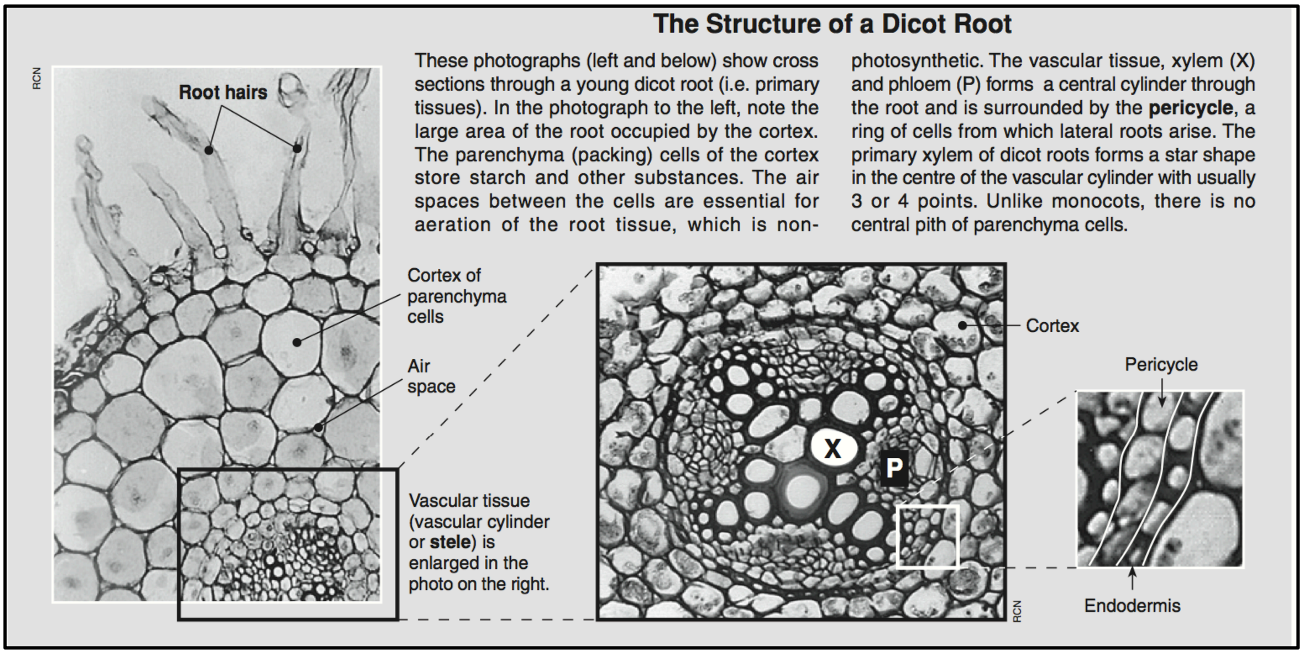
**End of topic checklist for 2.3 Transport**
Tick as appropriate:
RED: I do not know about this
AMBER: I have heard about this but have not learned this yet. I am unsure on this.
GREEN: I have heard about this and I have learned this. I am confident about this.

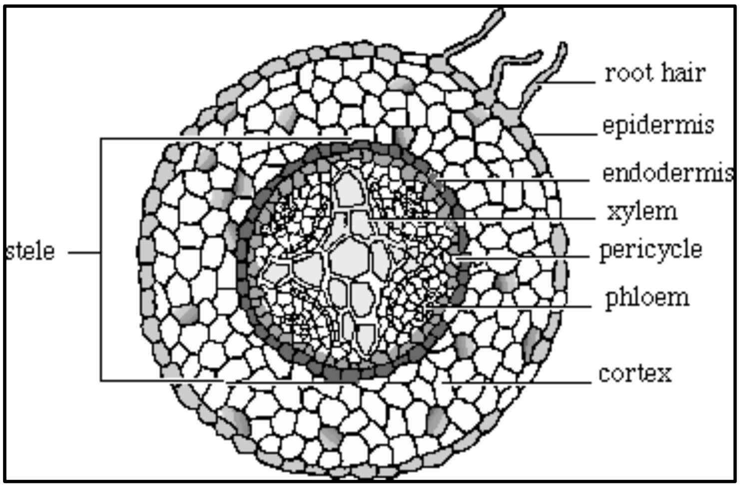
| | | | |
|---|---|---|---|
| 1. Candidates should be able to draw a dicotyledonous root to show position of vascular tissue. | | | |
| 2. Most absorption of water is through the root hairs, which provide a large surface area and are freely permeable. | | | |
| 3. Soil solution soaks into the walls of epidermal cells and travels across the cortex through the cell walls or through the spaces between cells, drawn by the transpiration stream; this is the apoplast route. | | | |
| 4. Water can also cross the plasma membrane by osmosis. | | | |
| 5. It them moves through the cytoplasm of cells via plasmodesmata; this is the symplast route. | | | |
| 6. Water can also travel through cell vacuoles; the vacuolar pathway. | | | |
| 7. The endodermis is a layer of cells that surround the pericycle within which lies the vascular tissue (stele). | | | |
| 8. The endodermic apoplast route is blocked by the Casparian band located tangentially in the cell wall and made of waterproof suberin. | | | |
| 9. At the Casparian band water passes across the plasma membrane and continues along the symplast route. | | | |
| 10. Since the xylem lacks cell contents the water is transferred to the apoplast in the pericycle. | | | |
| 11. Nitrogen usually enters the plant as nitrate ions/ammonium ions which diffuse along the concentration gradient into the apoplast stream but enter symplast by active transport against the concentration gradient and then flow via plasmodesmata in the cytoplasmic stream. | | | |
| 12. At the endodermis ions must be actively taken up to by-pass the Casparian band, which allows the plant to selectively take up ions at this point. | | | |
| 13. This lowers the water potential in the xylem, causing water to be drawn through the endodermis. | | | |
| 14. This produces a positive hydrostatic pressure inside the xylem, forcing water upwards. This positive pressure is known as root pressure. | | | |
| 15. Candidates should be able to draw the structure of the stem of a dicotyledon to illustrate the position of transporting tissue. | | | |
| 16. Xylem consists of dead, lignified tracheids and vessels with pits, supporting fibres and living parenchyma. | | | |
| 17. Tracheids and vessels form a continuous system of channels for water transport. | | | |
| 18. Water passes through the root to the xylem, up through the stem to the leaves where most evaporates. | | | |
| 19. The columns of water in the xylem are held up by the cohesive force between water molecules and the adhesive forces between water molecules and the hydrophilic lining of the xylem vessels. | | | |
| 20. Transpiration is the loss of water from the leaves which gives rise to the transpiration stream. The continued removal of water molecules from the top of the xylem vessels results in a tension causing a pull on the xylem column. | | | |
| 21. Transpiration is affected by various external factors such as temperature, humidity and air movement. | | | |
| 22. The opening and closing of stomatal pores can alter water loss through transpiration. | | | |
| 23. Plants can be classified, on the basis of structure in relation to the prevailing water supply, into hydrophytes, mesophytes and xerophytes. | | | |
| 24. Hydrophytes, e.g. water lily, live with their roots submerged in mud at the bottom of a pond and have floating leaves on the surface. | | | |
| 25. Hydrophytes have little need for support or transport tissues; have little or no cuticle and stomata only on the upper surface of their leaves. There are large air spaces present in both stem and leaf tissue. | | | |

| | | | |
|---|---|---|---|
| 26. Xerophytes have adapted to living under conditions of low water availability so have modified structures to prevent excessive water loss. | | | |
| 27. Marram grass demonstrates the role of a xerophyte with its leaf shape, sunken stomata, thick cuticle and hairs in reducing water loss. | | | |
| 28. Mesophytes are plants of temperate regions and flourish in habitats with adequate water supply. They need to survive unfavourable times of the year by shedding their leaves, surviving underground or as dormant seeds. | | | |
| 29. Phloem consists of sieve tubes and companion cells linked by plasmodesmata with fibres and parenchyma. | | | |
| 30. The products of photosynthesis are transported in soluble form (sucrose) to all parts of the plant in the phloem. | | | |
| 31. The leaves are a source of sugars and the growing regions act as a sink. | | | |
| 32. Early evidence about translocation of solutes was obtained from ringing experiments. | | | |
| 33. The technique of radioactive tracing combined with using aphid mouthparts demonstrated that translocation is a rapid process. | | | |
| 34. Radioisotope labelling using carbon dioxide combined with autoradiography shows that sucrose is transported bi-directionally to sinks. | | | |
| 35. The mass flow hypothesis suggests that there is a passive flow of sucrose from source to sink. (no details required) | | | |
| 36. The mass flow hypothesis does not account for all observations such as movement in opposite directions at the same time and at different rates. | | | |
| 37. Other hypotheses have been proposed; including diffusion and cytoplasmic streaming. | | | |

**Uptake and Transport of Water**
Plants and animals require water for essentially the same reasons. It is the medium in which all metabolic reactions take place; it is needed for hydrolysis and for the transport of solutes around the organism. In addition it provides turgor pressure, which helps to support the organism.

**Uptake of Water by the Roots**
The roots provide the surface through which water is taken up. Thousands of root hairs that are found just behind the root tip greatly increase the surface area for water uptake. The root hairs are confined to the part of the epidermis immediately behind the tip, further back they will be sloughed off through abrasion as the root pushes through the soil particles. Each root hair cell is a slender extension of an epidermal cell up to 4mm long.




The root hairs penetrate between the soil particles and are in close contact with the soil water. The root hairs are freely permeable to water and water enters the root from the soil, down a gradient of water potential.

Behind the epidermis, large thin-walled **parenchyma** cells make up the **cortex**, which constitutes the main body of the root. In the centre there is a core of vascular tissue, which contains lignified **xylem cells** and **phloem cells**.

The endodermis is a layer of cells, which surround the **pericycle** within which is the vascular tissue (**stele**).

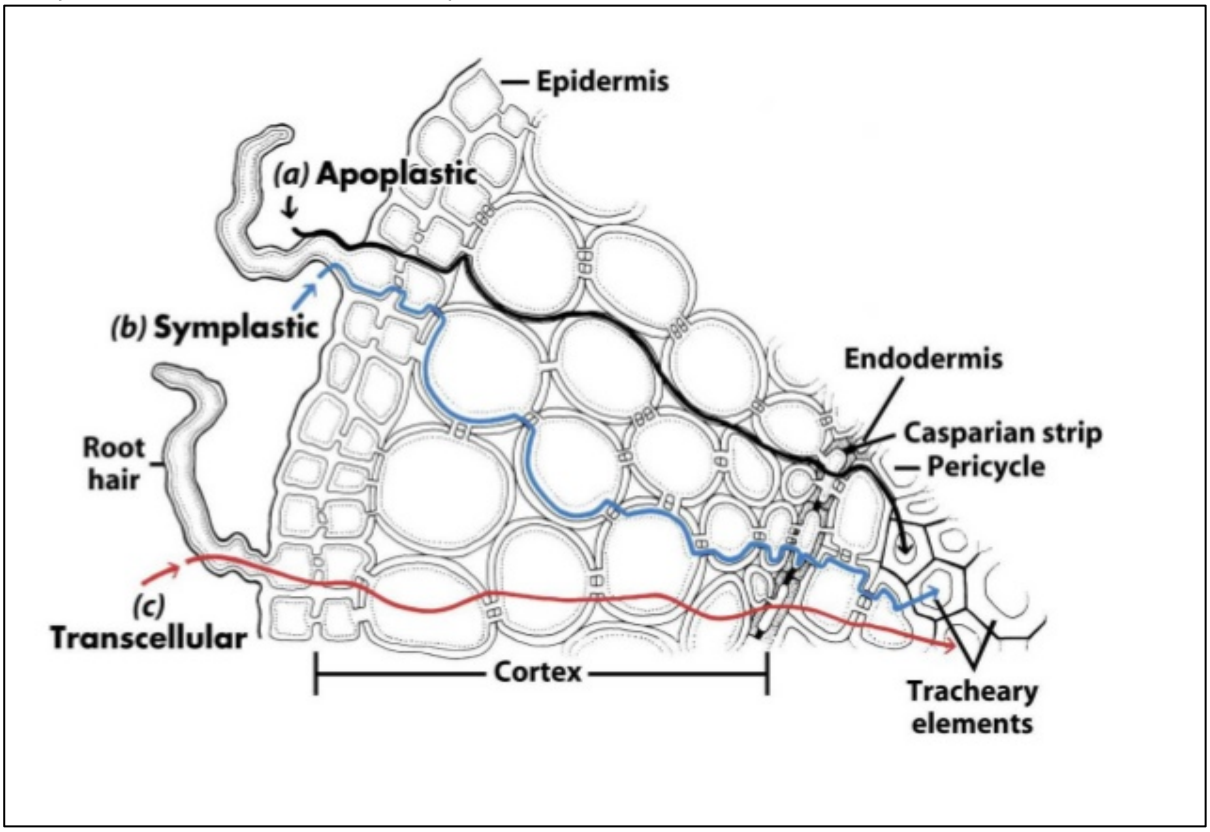
**Draw a simplified plan diagram of the root:**

**The pathway taken by water**
Water mainly enters the root down a water potential gradient. The soil water only contains a very weak solution of mineral salts and so has a high water potential.
Once inside the root the water follows three pathways across the cortex:

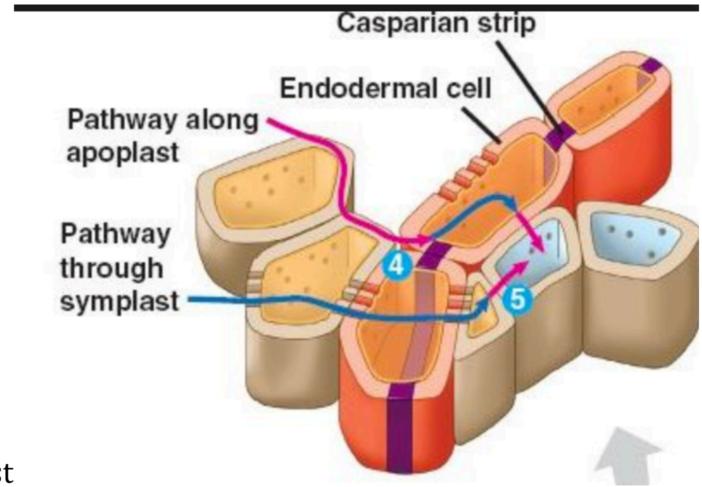
- The **apoplast pathway**: this pathway follows the interconnected cellulose cell walls of adjacent cells. The water flows in the spaces between the cellulose microfibrils, the pull is provided by the transpiration stream.

- The **symplast pathway**: this consists of the cytoplasm, which is continuous from cell to cell via the **plasmodesmata**. To reach the symplast (inside the cell membrane) water has to cross the partially permeable membrane by osmosis.

- The **vacuolar pathway** water passes across the epidermal cell wall, plasma membrane and tonoplast, then into the vacuole. It passes to the next cell in the same manner.



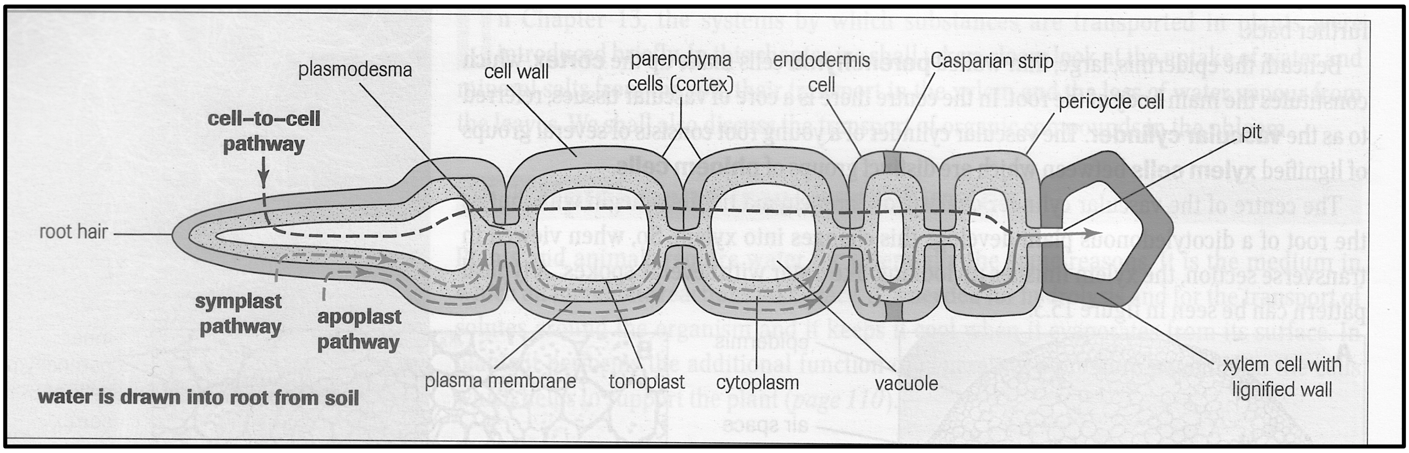

- Change the Transcellular to the **vacuolar pathway**
- Label some plasmodesmata
- Label a cellulose cell wall of a cell in which the **apoplast pathway** is taking place
- Label the symplast of a cell in which the **symplast pathway** is taking place.




Once the water reaches the **endodermis**, its flow is prevented by an impermeable thickening of **suberin** in the walls of endodermal cells, this is known as the **Casparian band**. This Casparian band diverts water from the cell walls, and prevents the use of the apoplast pathway, forcing it to take the symplast pathway through the endodermal cells.

It is thought that endodermal cells actively transfer salts from the cortex to the pericycle. The resulting high concentration of salts in the pericycle creates a

low water potential which cause water to move into them by osmosis from the cortex, through the partially permeable membranes of the endodermis cells.
In summary salts are actively transferred across the endodermis and the water follows passively. Once in the pericycle, the water flows into the xylem down a water potential gradient in both symplast and apoplast pathways. Once in the xylem due to the fact that xylem cells lack cell contents the water is transferred to the apoplast pathway.




**Uptake of Minerals**
Minerals such as ammonium and nitrate ions are usually taken up by the root hairs by active transport from the soil solution. Once absorbed, the mineral ions may move along the apoplast pathway carried into solution by the water and being pulled along by the transpiration stream.

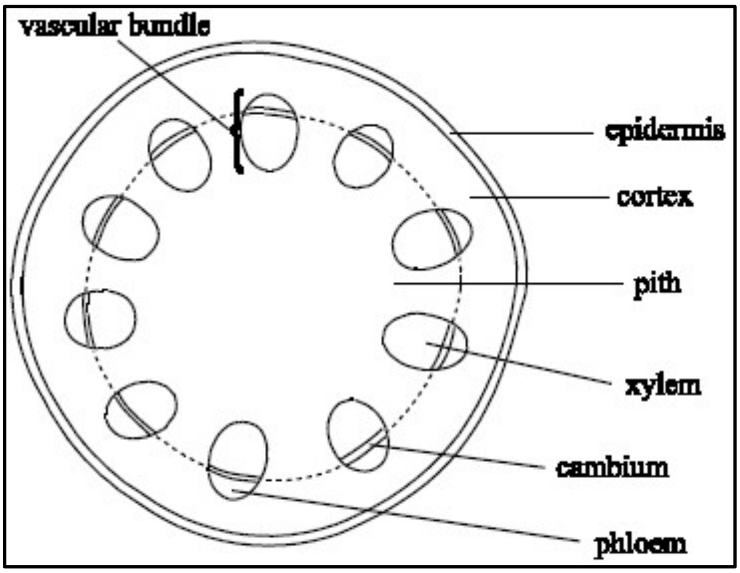
When minerals reach the endodermis and the **Casparian Band** the ions enter the cytoplasm of the cell by active transport from where they diffuse or are actively transported into the xylem. At the endodermis because ions need to be actively taken up this allows the plant to selectively uptake ions.

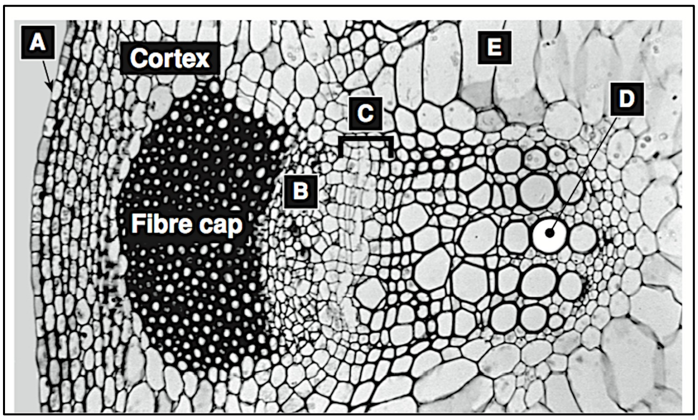
Describe the 3 routes along which water moves across the cortex of the root from the epidermal layer to the central tissue (note these 3 routes are also used as water moves from the xylem vessels across the mesophyll cells in the leaf).

Explain the role of the **Casparian Band** in the endodermis.

**Transport of Water from the Root to the Leaf**
Water is transported from the roots to the leaves via the stem.

**Internal Structure of the Stem**
In dicots, each vascular bundle contains **xylem** (to the inside) and **phloem** (to the outside). Between the phloem and the xylem is the **vascular cambium**; a layer of cells that divide to produce thickening of the stem. The middle of the stem is called the **pith**, it is filled with thin walled **parenchyma** cells.




Looking at the figure on the right hand side, which shows a light micrograph of part of a stem, try to identify parts A to E.

A________________________________________

B________________________________________

C________________________________________

D________________________________________

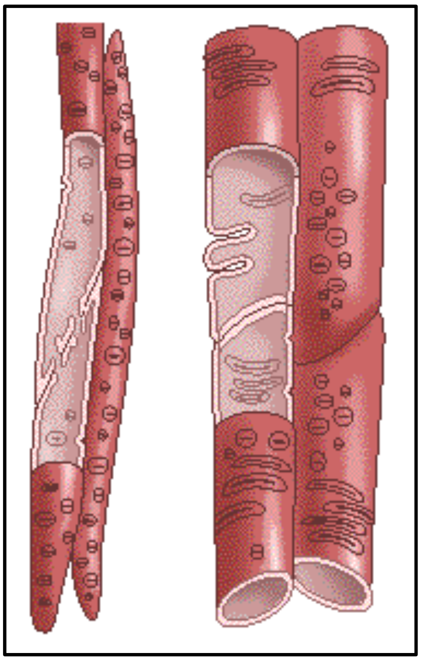
E________________________________________

Draw and label a plan diagram of a stem below:

**Xylem Tissue**

Xylem is the principal **water conducting tissue** in vascular plants. It is also involved in transporting dissolved minerals.

Xylem is a **complex tissue**. In angiosperms, it is composed of five cell types: tracheids, vessels, xylem parenchyma and fibres. Tracheids and vessels are the major transporting tissues; they are heavily strengthened with lignin. Parenchyma is involved in storage and fibres lend strength.
Xylem contains two types of conducting cells: **tracheids** and **vessels**. These are dead cells and they form a system of pipes through which water can travel. The cells are dead because once that have reached their full size, their cellulose cell walls become impregnated with **lignin**, which is impermeable to water, and solutes. The cells die leaving the cell walls surrounding a fluid filled cavity. Lignin also provides strength.



Cell A Cell B

Vessels are characteristic of angiosperm and are absent from the xylem tissue of conifers. Tracheids occur in all conifers and all angiosperms.

Vessels provide little resistance to the movement of water this is because the end walls of the vessels have broken down and form a continuous cylindrical pipe.

Tracheids provide more resistance as the end walls remain intact and are perforated only by small holes called **pits**.

Pits occur in the walls of both vessels and tracheids. Where a pit occurs lignin fails to deposit and only cellulose remains. This permits the passage of water sideways as well as upwards.

Name cells A and B.

______________________________________________

State one way in, which the structure of cell A differs from, cell B.

______________________________________________

In which tissue are these cells found?

______________________________________________

State two functions of these tissues:

______________________________________________

______________________________________________

Describe 3 ways in which cell B is adapted for its function in the plant.

______________________________________________

______________________________________________

______________________________________________

______________________________________________

Give two functions of lignin

______________________________________________

______________________________________________

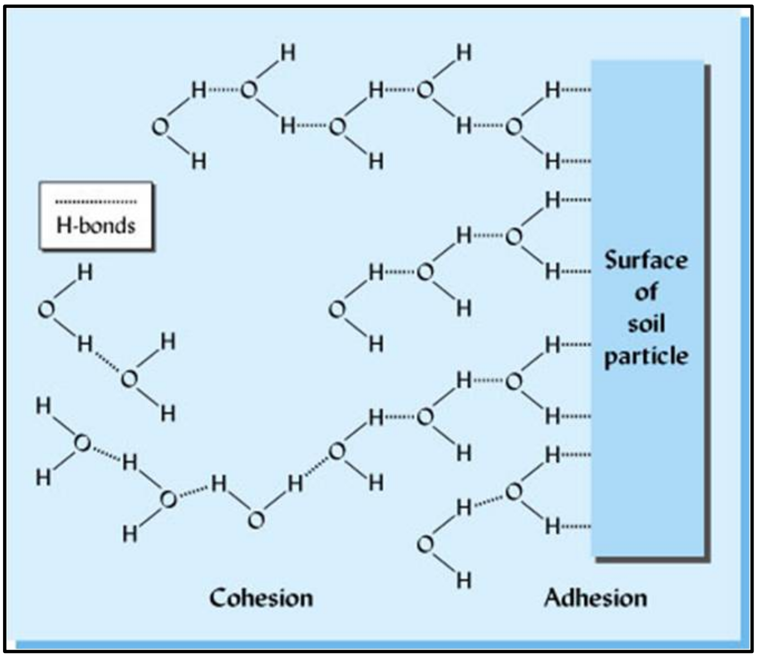
**The Ascent of Water up the Stem**

**Root Pressure**
This is as a result of osmotic flow across the endodermis, the necessary water potential gradient being created by the active transport of salts from the cortex to the pericycle (see page 5).

Root pressure provides a force that pushes water up the stem.

**Transpiration**
Water travels up through the stem into the leaves, where most of it evaporates from the internal leaf surface and passes out as water vapour, into the atmosphere. The water lost in this way is replaced by water drawn up through the xylem tubes in what is called the **transpiration stream**. Continuous columns of water therefore hang from the top of the plant; two forces holding them there are **adhesion** and **cohesion**.

Distinguish between the terms adhesions and cohesion (include why water is exhibits these properties):

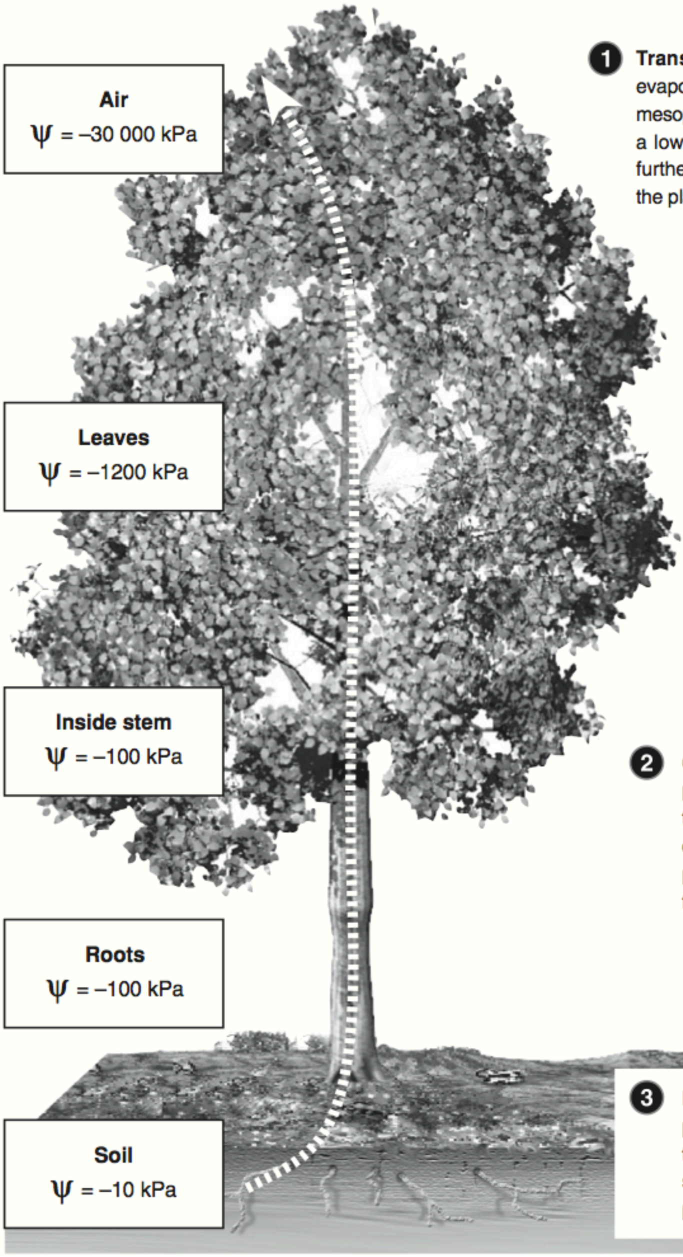



The lining of the xylem vessels is hydrophilic, why is this important?

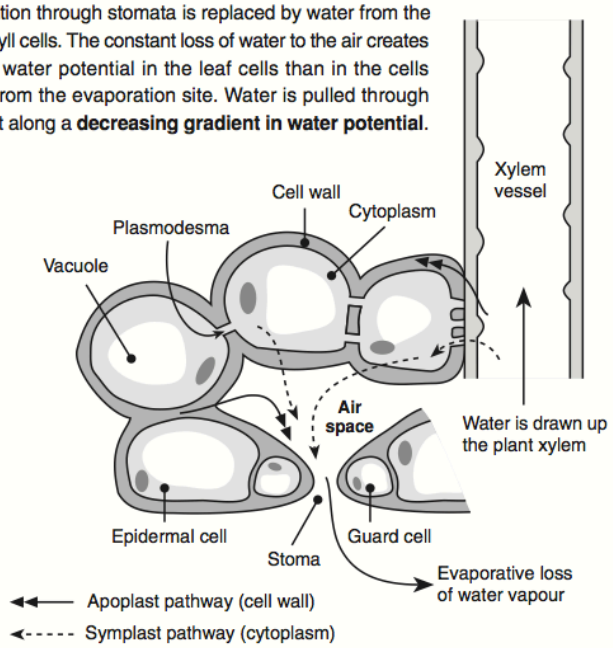
The **cohesion-tension** theory is often used to explain the rise of water in the xylem of all plants. Cohesive forces between water molecules hold the continuous columns of water together, and when water transpires from the leaf the whole of the water column moves up the plant.

**From Leaf to the Air**
The stomata as well as permitting the entry of carbon dioxide, allow the evaporation of water from the plant, the phenomenon known as **transpiration**. The effective evaporating surface of the leaf consists of saturated spongy mesophyll cells. The water evaporates and moves down a gradient of water potential from the plant to the atmosphere, through the stomatal pores.

Plants lose water all the time, despite the adaptations they have to help prevent it (e.g. waxy leaf cuticle). Approximately 99% of the water a plant absorbs from the soil is lost by evaporation from the leaves and stem. This loss, mostly through stomata, is called **transpiration** and the flow of water through the plant is called the **transpiration stream**. Plants rely on a gradient in water potential ($\psi$) from the roots to the air to move water through their cells. Water flows passively from soil to air along a gradient of decreasing water potential. The gradient in water potential is the driving force in the ascent of water up a plant. A number of processes contribute to water movement up the plant: transpiration pull, cohesion, and root pressure. Transpiration may seem to be a wasteful process, but it has benefits. Evaporative water loss cools the plant and the transpiration stream helps the plant to maintain an adequate mineral uptake, as many essential minerals occur in low concentrations in the soil.




**1 Transpiration pull**: Water lost from the air spaces by evaporation through stomata is replaced by water from the mesophyll cells. The constant loss of water to the air creates a lower water potential in the leaf cells than in the cells further from the evaporation site. Water is pulled through the plant along a **decreasing gradient in water potential**.




**2 Cohesion**: The transpiration pull is assisted by the special **cohesive** properties of water. Water molecules cling together as they are pulled through the plant and they **adhere** to the walls of the xylem. This creates one unbroken column of water through the plant. The upward pull on the cohesive sap creates a tension (a negative pressure). This facilitates water uptake and movement through the plant.

**3 Root pressure**: Water entering the stele from the soil creates a **root pressure;** a weak 'push' effect for the water's upward movement through the plant. Root pressure can force water droplets from some small plants under certain conditions (**guttation**), but generally it is plays a minor part in the ascent of water.

1. (a) Plants constantly lose water by transpiration. Explain how plants compensate for this: ____________________

   ________________________________________

   (b) Describe one benefit of the transpiration stream for a plant: ____________________

   ________________________________________

2. Briefly describe three processes that assist the transport of water from the roots of the plant upward:

   (a) ________________________________________

   (b) ________________________________________

   (c) ________________________________________

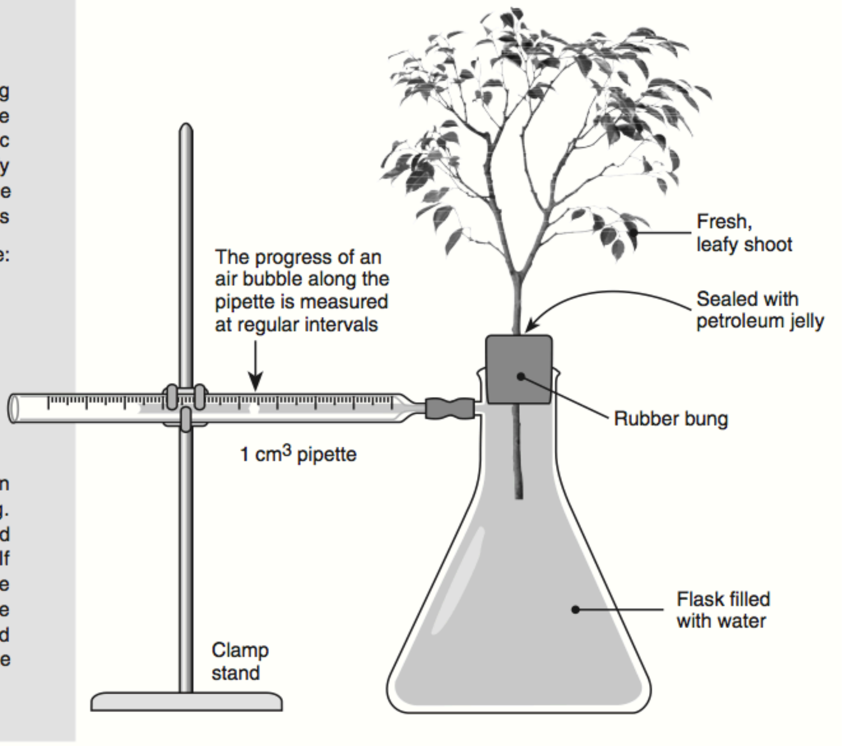
## The Potometer

A potometer is a simple instrument for investigating transpiration rate (water loss per unit time). The equipment is simple and easy to obtain. A basic potometer, such as the one shown right, can easily be moved around so that transpiration rate can be measured under different environmental conditions

Some of the physical conditions investigated are:

- Humidity or vapour pressure (high or low)
- Temperature (high or low)
- Air movement (still or windy)
- Light level (high or low)
- Water supply

It is also possible to compare the transpiration rates of plants with different adaptations e.g. comparing transpiration rates in plants with rolled leaves vs rates in plants with broad leaves. If possible, experiments like these should be conducted simultaneously using replicate equipment. If conducted sequentially, care should be taken to keep the environmental conditions the same for all plants used.




3. Describe three environmental conditions that increase the rate of transpiration in plants, explaining how they operate:

(a) ____________________

(b) ____________________

(c) ____________________

4. The **potometer** (above) is an instrument used to measure transpiration rate. Briefly explain how it works:

____________________

____________________

5. An experiment was conducted on transpiration from a hydrangea shoot in a potometer. The experiment was set up and the plant left to stabilise (environmental conditions: still air, light shade, 20°C). The plant was then subjected to different environmental conditions and the water loss was measured each hour. Finally, the plant was returned to original conditions, allowed to stabilise and transpiration rate measured again. The data are presented below:

| Experimental conditions | Temperature / °C | Humidity / % | Transpiration / $gh^{-1}$ |
|---|---|---|---|
| (a) Still air, light shade, 20°C | 18 | 70 | 1.20 |
| (b) Moving air, light shade, 20°C | 18 | 70 | 1.60 |
| (c) Still air, bright sunlight, 23°C | 18 | 70 | 3.75 |
| (d) Still air and dark, moist chamber, 19.5°C | 18 | 100 | 0.05 |

(a) Name the control in this experiment: ____________________

____________________

(b) Identify the factors that increased transpiration rate, explaining how each has its effect: ____________________

____________________

____________________

(c) Suggest a possible reason why the plant had such a low transpiration rate in humid, dark conditions:

____________________

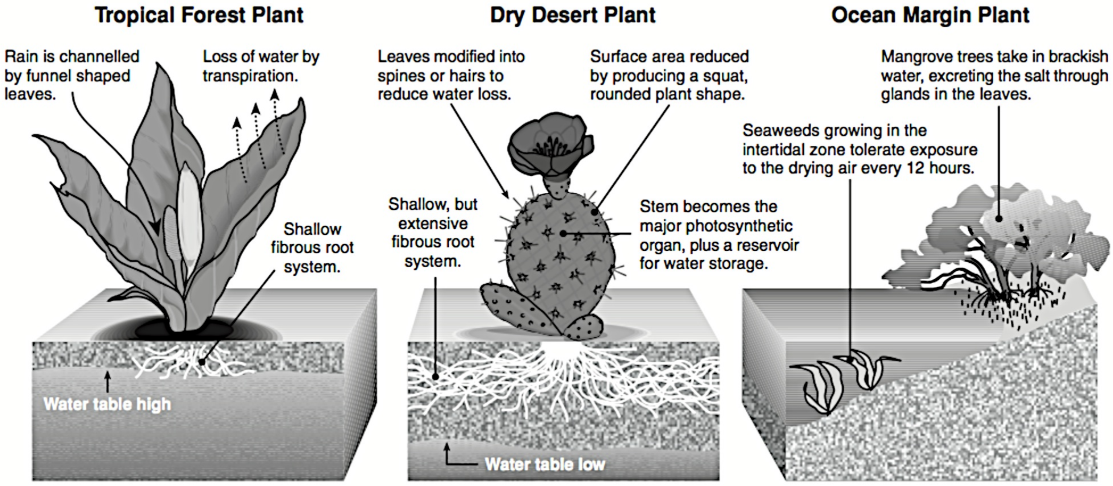
____________________

## Mesophytes, Xerophytes and Hydrophytes

Plants can be classified on their basis of their structure in relation to the availability of water. **Mesophytes** are plants found in temperate regions and they flourish in habitats with adequate water supply. They survive unfavourable times of the year by shedding their leaves, surviving underground as tubers and bulbs or as dormant seeds.

### Xerophytes

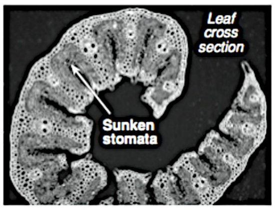
Without sufficient water plant cells lose **turgor** and the tissue wilts. If a plant passes its **permanent wilting point** it will die. Water is lost from the plant by **transpiration**: the loss of water vapour, primarily through the stomata. Water balance is not a problem for aquatic plants; they allow water to flow in by osmosis until the cell wall stops further expansion. Plants adapted to dry conditions are called **xerophytes** and they show structural (xeromorphic) and physiological adaptations for water conservation. Some of these are outlined below. Halophytes (salt tolerant plants) and alpine species may also show xeromorphic features in response to the scarcity of obtainable water and high transpirational losses in these environments.




Tropical plants live in areas of often high rainfall. There is also a corresponding high transpiration rate. Water availability is not a problem in this environment.

Desert plants e.g. cacti, cope with low rainfall and high transpiration rates. Plants develop strategies to reduce water loss, store water, and access available water supplies.

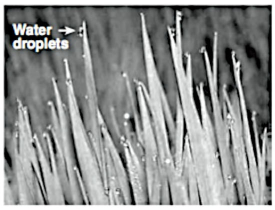
Land plants that colonise the shoreline (e.g. mangroves) must cope with high salt content in the water. Seaweeds below low tide do not have a water balance problem.




Grasses living in dry areas curl their leaves and have sunken stomata.

Mosses are poor at obtaining and storing water, restricting distribution.


Hairs on leaves trap air close to the surface, reducing transpiration rate.

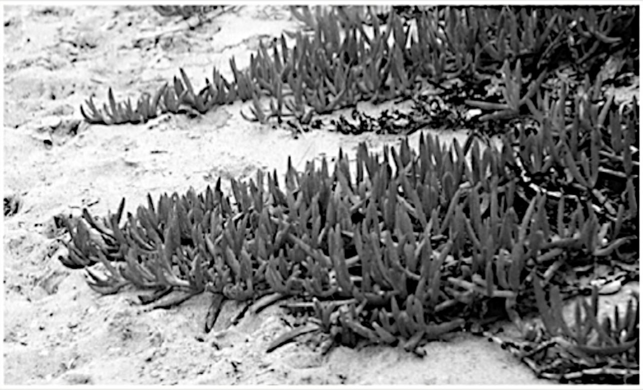



Excess water is forced from leaves (guttation) during high humidity.

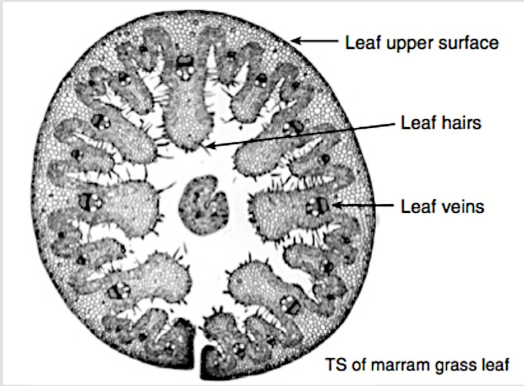
**Methods of water conservation in various plant species**

| Adaptation for water conservation | Effect of adaptation | Example |
|---|---|---|
| Thick, waxy cuticle to stems and leaves | Reduces water loss through the cuticle. | *Pinus* sp. ivy (*Hedera*), sea holly (*Eryngium*), prickly pear (*Opuntia*). |
| Reduced number of stomata | Reduces the number of pores through which water loss can occur. | Prickly pear (*Opuntia*), *Nerium* sp. |
| Stomata sunken in pits, grooves, or depressions<br>Leaf surface covered with fine hairs<br>Massing of leaves into a rosette at ground level | Moist air is trapped close to the area of water loss, reducing the diffusion gradient and therefore the rate of water loss. | **Sunken stomata**: *Pinus* sp., *Hakea* sp.<br>**Hairy leaves**: lamb's ear. **Leaf rosettes**: dandelion (*Taraxacum*), daisy. |
| Stomata closed during the light, open at night | CAM metabolism: $CO_2$ is fixed during the night, water loss in the day is minimized. | **CAM plants**, e.g. American aloe, pineapple, *Kalanchoe*, *Yucca*. |
| Leaves reduced to scales, stem photosynthetic<br>Leaves curled, rolled, or folded when flaccid | Reduction in surface area from which transpiration can occur. | **Leaf scales**: broom (*Cytisus*). **Rolled leaf**: marram grass (*Ammophila*), *Erica* sp. |
| Fleshy or succulent stems<br>Fleshy or succulent leaves | When readily available, water is stored in the tissues for times of low availability. | **Fleshy stems**: *Opuntia*, candle plant (*Kleinia*). **Fleshy leaves**: *Bryophyllum*. |
| Deep root system below the water table | Roots tap into the lower water table. | Acacias, oleander. |
| Shallow root system absorbing surface moisture | Roots absorb overnight condensation. | Most cacti |

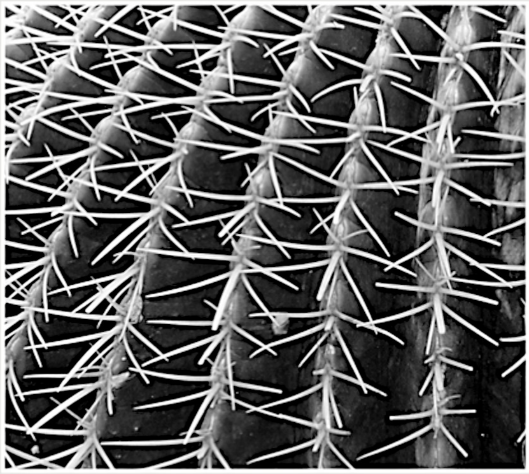
## Adaptations in halophytes and drought tolerant plants



**Ice plant** (*Carpobrotus*): The leaves of many desert and beach dwelling plants are fleshy or succulent. The leaves are triangular in cross section and crammed with water storage cells. The water is stored after rain for use in dry periods. The shallow root system is able to take up water from the soil surface, taking advantage of any overnight condensation.




**Marram grass** (*Ammophila*): The long, wiry leaf blades of this beach grass are curled downwards with the stomata on the inside. This protects them against drying out by providing a moist microclimate around the stomata. Plants adapted to high altitude often have similar adaptations.



**Ball cactus** (*Echinocactus grusonii*): In cacti, the leaves are modified into long, thin spines which project outward from the thick fleshy stem (see close-up above right). This reduces the surface area over which water loss can occur. The stem takes over the role of producing the food for the plant and also stores water during rainy periods for use during drought. As in succulents like ice plant, the root system in cacti is shallow to take advantage of surface water appearing as a result of overnight condensation.

1. Explain the purpose of **xeromorphic** adaptations: ______

2. Describe three xeromorphic adaptations of plants:

   (a) ______

   (b) ______

   (c) ______

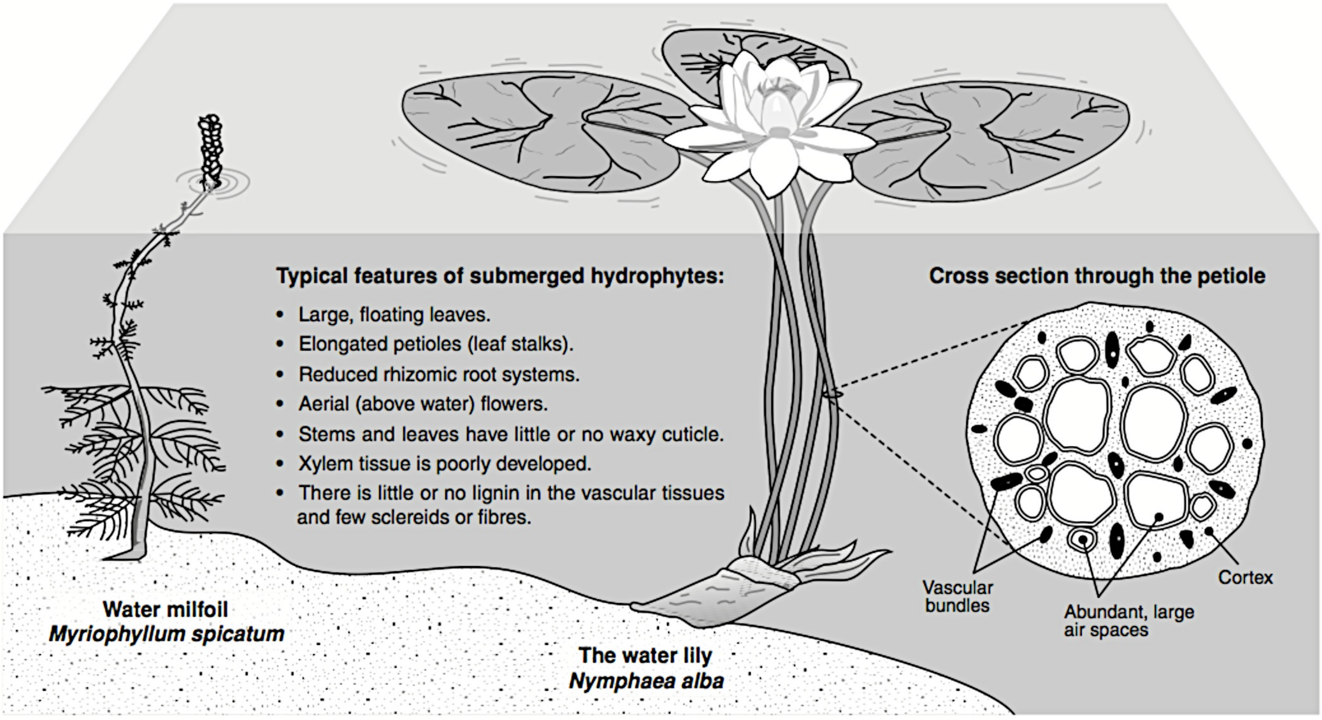
3. Describe a physiological mechanism by which plants can reduce water loss during the daylight hours:

4. Explain why creating a moist microenvironment around the areas of water loss reduces transpiration rate:

5. Explain why seashore plants (halophytes) exhibit many desert-dwelling adaptations: ______

## Hydrophytes

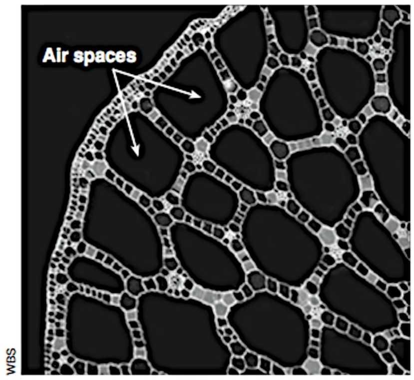
**Hydrophytes** are a group of plants that have adapted to living either partially or fully submerged in water. Survival in water poses different problems to those faced by terrestrial plants. Hydrophytes have a reduced root system, a feature that is often related to the relatively high concentration of nutrients in the sediment and the plant's ability to remove nitrogen and phosphorus directly from the water. The leaves of submerged plants are thin to increase the surface area of photosynthetic tissue and reduce internal shading. Hydrophytes typically have no cuticle (waterproof covering) or the cuticle is very thin. This enables the plant ability to absorb minerals and gases directly from the water. In addition, being supported by the water, they require very little in the way of structural support tissue.





*Myriophyllum*'s submerged leaves are well spaced and taper towards the surface to assist with gas exchange and distribution of sunlight.

The floating leaves of water lilies (*Nymphaea*) have a high density of stomata on the upper leaf surface so they are not blocked by water.




Cross section through *Potamogeton*, showing massive air spaces which assist with flotation and gas exchange.

1. Explain how the following adaptations assist hydrophytes to survive in an aquatic environment:

   (a) Large air spaces within the plants tissues: ______________________

   ______________________

   (b) Thin cuticle: ______________________

   ______________________

   (c) High stomatal densities on the upper leaf surface: ______________________

   ______________________

2. Explain why hydrophytic plants have retained an aerial (above water) flowering system: ______________________

______________________

# Bio Factsheet

www.curriculum-press.co.uk Number 146

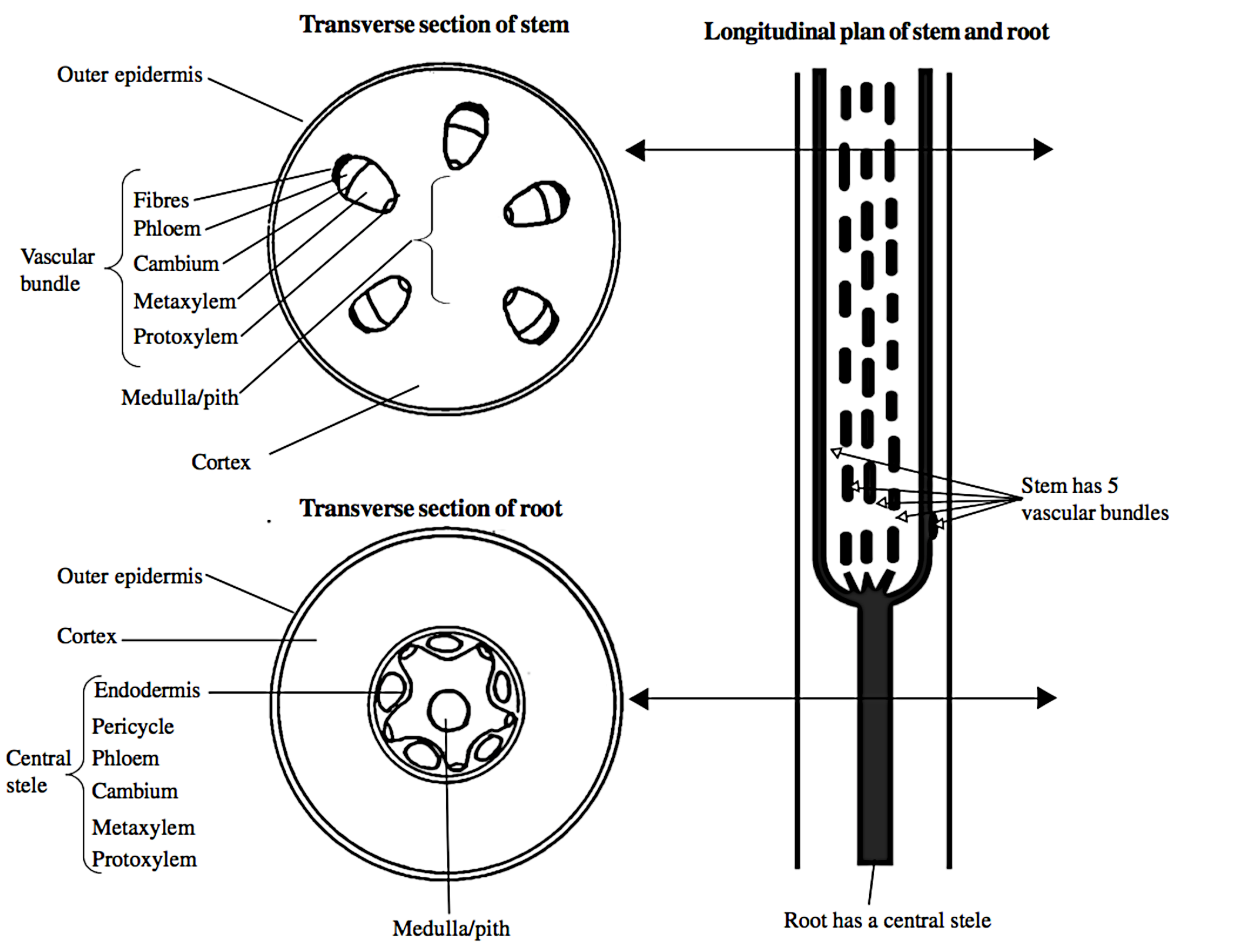
# Tracheids, Vessels and Sieve Tubes

Tracheids, vessels and sieve tubes are found in the **vascular tissue** of the plant.

- Tracheids and vessels are found in the **xylem** tissue and conduct water and dissolved mineral ions from the roots to the aerial parts of the plant.
- Sieve tubes are found in the **phloem** tissue and conduct organic solutes, for example, sugars and amino acids, up and down the plant, from where they are synthesised to where they are required.

Xylem and phloem are characteristic of the higher plants called Tracheophytes, which include ferns, conifers and flowering plants. Lower plants such as liverworts and mosses do not develop xylem or phloem. The special water conducting cell known as the tracheid is characteristic of the xylem tissue in ferns and conifers. In flowering plants, although some tracheids may be present, a more specialised system of water conducting xylem vessels has evolved.

**Fig 1. Distribution of vascular tissue in stem and root of a dicotyledonous flowering plant, for example, buttercup**



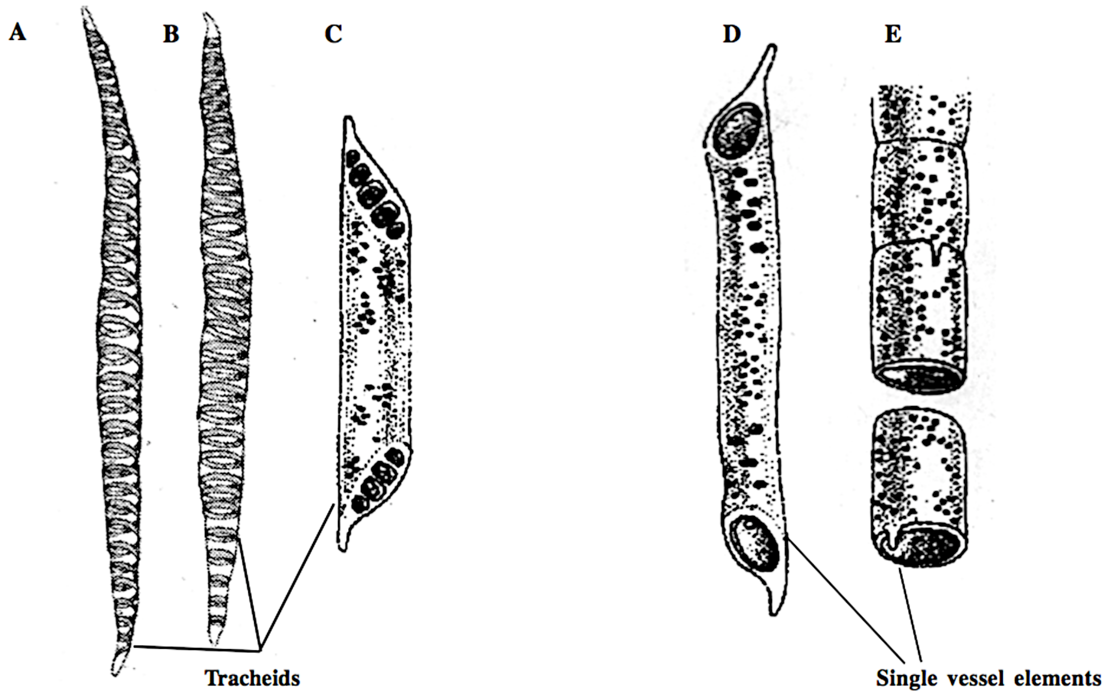

- Protoxylem is the first to differentiate and has a structure, which although suitable for conducting water and dissolved minerals up the plant, enables the growing plant to still elongate.
- Metaxylem develops later and in greater bulk than protoxylem. It will not allow further elongation of the plant, but besides being adapted to transport water and minerals it also has a mechanical strengthening and supporting function in the plant.
- Fibres are additional elongated, lignified (see below) cells which provide extra strength and stability to the stem and to the soft phloem tissue in particular. The pericycle in many roots is also made up of fibres.
- Cambium consists of cells that can divide by mitosis and then differentiate into extra xylem and phloem tissue. This happens in plants (trees) that become woody and is referred to as 'secondary growth'.

**Development of Xylem**

Xylem (and phloem) develop first in the zone of differentiation behind the apical meristems (growing points). Xylem develops from undifferentiated living plant cells which have cellulose walls. The cells become **elongated** and their walls become impregnated with **lignin**.

Lignin is a complex non-carbohydrate polymer which is laid down on the primary cellulose walls of the water-transporting cells and tubes of xylem. The process is called **lignification** and because lignin is impermeable the contents of lignified cells die, leaving hollow tubes for water transport.

**Fig 2. Types of xylem water-conducting elements**




**A and B:** These cells are tracheids because their ends are not yet perforated with one large hole. These primitive tracheids are characteristic of the protoxylem of conifers, and the lignin is laid down in rings (annular thickening) or in a spiral (spiral thickening). This enables further elongation of the stem or root during growth. If the lignin was laid down in a solid fashion it would prevent elongation. The water and dissolved salts can pass from cell to cell through the non-lignified areas of the wall, particularly at the non-lignified tapering ends.

Protoxylem vessels in flowering plants also have annular and spiral thickening.

**C:** This is a more advanced type of tracheid, characteristic of the metaxylem of conifers. This type of cell may also be found dispersed amongst the vessels in the xylem of some flowering plants. The lignin is laid down in a solid mass, but has pits which align with pits on adjacent tracheids to allow lateral transport of water. The end walls are perforated with several large holes to allow easy passage of water upwards, from tracheid to tracheid.

**D and E:** D is a single vessel element. The end wall has completely perforated so that water can easily pass up the vessel. E shows a vessel in which several vessel elements are joined end to end. Such a vessel may contain hundreds of vessel elements and stretch from the roots to the leaves of a tall tree. Vessels of this sort are characteristic of the metaxylem and secondary xylem (wood) of flowering plants.

**Mechanism of water movement up the xylem of a tall plant**

The stream of water (and dissolved salts) which passes up the xylem from the water absorbing areas of the root to the leaves is called the **transpiration stream.**

The transpiration stream in tall plants is unique in that it flows uphill. The force of gravity is overcome by strong forces caused in the leaves by **transpiration**. This process is driven by heat from the Sun, which causes water on the external surfaces of the mesophyll cells to evaporate, forming water vapour, which diffuses from the leaves, mainly via stomata. The loss of water from a mesophyll cell lowers the water potential of that cell causing water to move into the mesophyll cell, by osmosis, from an adjacent cell. Thus a water potential gradient becomes established, causing water to be drawn from the xylem into the mesophyll cells.

The continuous, unbroken column of water in the xylem vessels, from the deepest roots to the highest shoot tips, is thought to be maintained by **cohesion** and **adhesion**.

- Water has unique **cohesive** properties, by which hydrogen bonds between water molecules hold the water molecules together, giving the water column high tensile strength. This prevents the water column from breaking apart as it is pulled upwards. The loss of water from the xylem to the mesophyll creates a pulling force (**tension**) in the water column. The tension is transmitted all the way down to the roots, maintaining the integrity of the entire water column.
- **Adhesion**, which is a force of attraction between unlike molecules, occurs between the water molecules and the lignified walls of the xylem vessels This force prevents the water column from slipping back down towards gravity. Therefore, by a combination of tension, cohesion, and adhesion, water moves up the stem.

***Remember*** *– atmospheric pressure will help to support the column of water in the xylem. However, a pressure of 1 atmosphere at sea level will only support a column of water 10.4 metres high. Some trees reach a height of around 120 metres and so, if relying on atmospheric pressure, would need a pressure of around 11.5 atmospheres to maintain the water column in the xylem. Thus cohesion and adhesion are of paramount importance.*

As water is drawn up the xylem, by the transpiration pull, it is replaced because water is drawn into the xylem from the cortex cells of the root. This maintains a water potential gradient across the root cortex to the root hairs and causes the root hairs to absorb more water from the soil solution.

***Exam Hint:*** *Candidates sometimes refer to the sum of the forces interacting to hold water in the xylem tubes is as* ***capillarity****. This is not quite true. Capillarity is a force that will hold a column of water in a narrow glass tube which has water compatible (hydrophilic) surfaces. Although capillarity may aid support of the water column in small herbaceous plants it is not great enough to support a column of water the height of a tree.*

***Remember:*** *that xylem tubes need to be narrow so that forces of adhesion, cohesion, tension and capillarity are great relative to the small water volume but need to be wide enough to carry the volumes of water required. This is why xylem tends to contain many small vessels rather than a few large ones.*

Another force, not completely understood, involved in water transport up the xylem is **root pressure**. This force rarely exceeds 2 atmospheres and so can only support a water column of up to a metre. The pushing force requires ATP and apparently originates from active transport mechanisms transferring ions from root cortex to xylem across the pericycle and endodermis.

**Structure of phloem tissue**
The main structures found in phloem are **sieve tubes** and **companion cells**. Each sieve tube is
a cylindrical column of sieve tube elements, joined end to end.

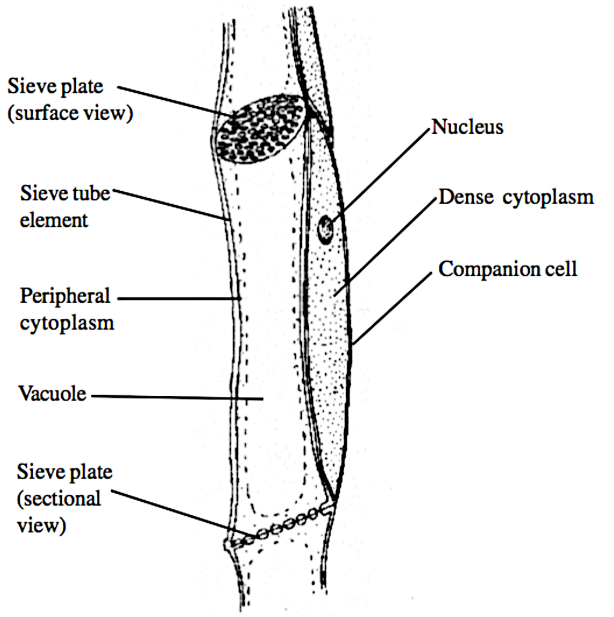
- Each sieve tube is a cylindrical column of **sieve tube elements** joined end to end. The end walls are perforated by pores, through which pass enlarged **plasmodesmata** (cytoplasmic strands passing through the cell walls), forming structures called **sieve plates,** so called because they look like a sieve. When maturing, a sieve tube element loses its nucleus and its cytoplasm becomes pushed to the sides of the cell. Sieve tube elements are kept alive and supported in their function by **companion cells.**

- A typical companion cell has dense cytoplasm containing the normal organelles, but it has an unusually thin cellulosic cell wall and a vacuole, is usually absent. Companion cells have a very high number of mitochondria, indicating that they have a high metabolic rate. Companion cells are closely connected to sieve tube elements via numerous plasmodesmata.

A sieve tube and its companion cells forms a functional unit for **translocation** of organic solutes in the phloem. Sieve tubes will not work without their companion cells. A sieve tubes may consist of hundreds of sieve tube elements and stretch from the leaves to the roots or stem tips or flowers.

In deciduous trees the phloem sieve plates become blocked with callose just prior to leaf fall. Thus the phloem becomes inoperative during the dormant, unfavourable, leafless seasons.

**Fig 3. Longitudinal section of a sieve tube element and its companion cell**




**Translocation of organic solutes in the phloem**
The solution carried in the phloem is called **sap**. It contains organic solutes, for example, the disaccharide sucrose, amino acids, plant growth substances and some inorganic salts which have been transferred from the xylem.
The solutes are translocated (carried) from their **sources**, where they are made, to the **sinks**, were they are used. The photosynthetic leaves are the main sources and the growing regions are the main sinks. Storage areas, for example potato or dahlia tubers, act as sinks when the substances brought to them are stored and act as sources when the stored substances are broken down and the products released for use elsewhere in the plant.
Sucrose reaching the storage areas is hydrolysed to glucose and fructose, the fructose is then isomerised to glucose and the glucose is polymerized to the storage polysaccharide, starch. When glucose is required the starch can be broken down to release glucose into the phloem.
Translocation has been experimentally studied in three main ways:-

- **Ringing experiments.** A complete ring of bark, which includes the phloem but not the xylem, is removed from a woody stem. The tissue above the ring swells but the tissue beneath the ring withers. Chemical analysis of the fluid in the swollen tissue shows high concentrations of sugars and other organic solutes, but the tissue beneath the ring is deprived of nutrients, because the removal of the phloem impedes the downward flow of organic solutes. Water and salts can still pass upwards past the ring because the xylem tissue is intact.

- **Sap-sucking aphids.** Aphids feed on the phloem sap by piercing the phloem sieve tubes with their needle-like mouthparts (stylets). If the head of a feeding aphid is detached from the mouthparts, sap continues to exude from the stylet end. The flow can continue for days and the sap can be collected and analyzed. The closer the stylet is to a sugar source (photosynthesizing leaves or starch store) the higher the sugar content of the collected sap and the greater the rate of sap seepage from the stylet. This supports the idea that sugar is actively pumped into the sieve tubes at the source end, generating pressure to cause sap flow. If the phloem is treated with a metabolic inhibitor, such as cyanide, the sap flow ceases. This also suggests an active mechanism for phloem sap flow.

- **Radioactive tracers.** The radioactive isotope $^{14}C$ can be used to label carbon dioxide which is then utilized by the plant in photosynthesis. The movement of the radioactively labelled photosynthetic products, such as sucrose, can be traced through the stem using photographic film, which blackens where it is exposed to radioactivity. These blackened areas correspond to the position of the phloem. The technique is called **autoradiography**.

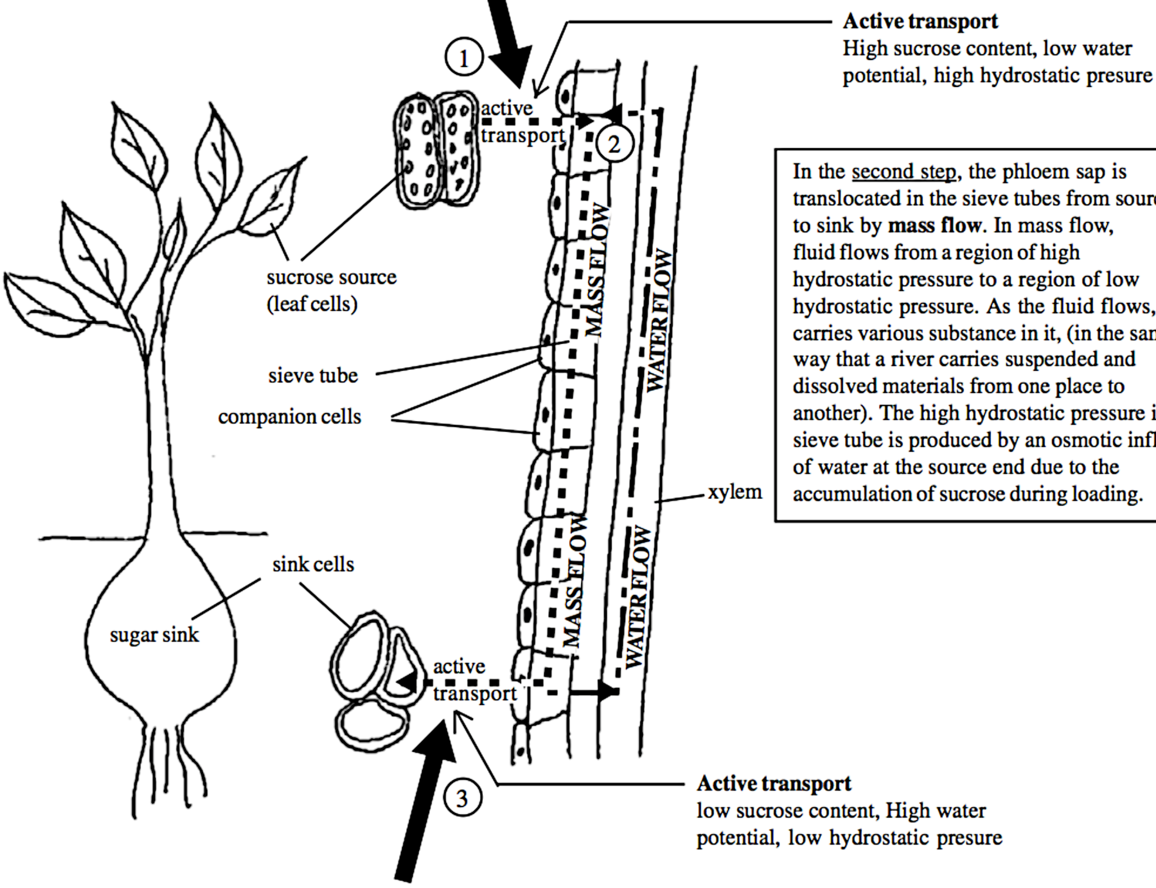
The techniques described above have yielded the following information about translocation of organic solutes:-
- Translocation takes place mainly in phloem sieve tubes.
- Translocation takes place over large distances.
- It is an active process which only occurs in living tissue.
- It is inhibited by metabolic poisons and lack of oxygen.
- Large quantities of organic substances can be translocated.
- The rate of translocation varies for different organic substances (a distance between 20 and 600 cm travelled per hour).
- Different organic substances can be translocated up and down the plant simultaneously (but probably not in the same sieve tube).
- In temperate plants, an increase in temperature between 10'C and 30'C will increase the rate and amount of translocation.

Translocation does not occur by diffusion because diffusion is too slow to enable the fast rates of translocation or the large quantities translocated. Also, substances that cannot diffuse, for example, viruses, are translocated in the phloem.

The most popular hypothesis used to explain translocation is the **pressure flow hypothesis**. This suggests that translocation involves a combination of active transport and mass flow, and takes place in three steps. These are shown in Fig. 4.

**Fig 4. The pressure flow hypothesis**

The first step occurs at a source (a leaf) in which a sieve tube becomes loaded with sucrose and other organic solutes. The loading is carried out by specialized companion cells (called **transfer cells**) and involves an active transport mechanism. The sucrose concentration in the sieve tubes may rise to 30% whereas the concentration in the leaf (mesophyll) cells remains around 0.5%. Transfer cells have many internal projections of the cell wall giving the cell membrane a very large area for transport. The cells also have very large numbers of mitochondria which generate the energy required for active transport.



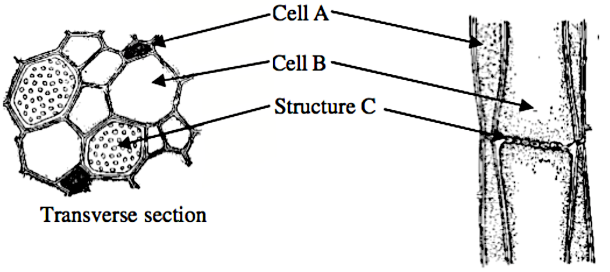

In the second step, the phloem sap is translocated in the sieve tubes from source to sink by **mass flow**. In mass flow, fluid flows from a region of high hydrostatic pressure to a region of low hydrostatic pressure. As the fluid flows, it carries various substance in it, (in the same way that a river carries suspended and dissolved materials from one place to another). The high hydrostatic pressure in a sieve tube is produced by an osmotic influx of water at the source end due to the accumulation of sucrose during loading.

In the third step, sucrose and other organic solutes are unloaded at the sink where they are used or converted into a storage product. Water osmotically follows the solutes out of the sieve tube, which lowers the hydrostatic pressure and so maintains the pressure gradient from source to sink. Unloading is probably an active process requiring living companion cells and energy.

The pressure flow hypothesis is probably only part of the mechanism for phloem transport. For instance, it does not give a role to the sieve plates and does not take into account the cytoplasmic streaming that occurs in sieve tubes.

**Practice Questions**

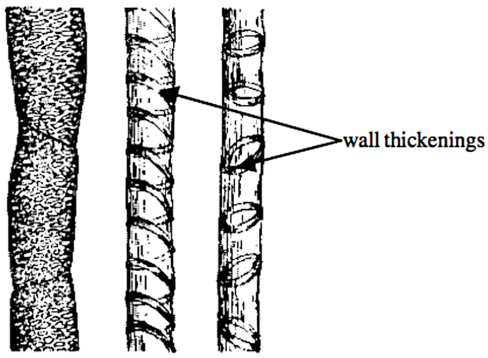
1. The drawings show a plant tissue cut in transverse and longitudinal sections.




(a) (i) Identify this tissue. 1
(ii) Name cells A and B and structure C. 3
(iii) In a deciduous tree what change occurs to structure C just prior to leaf fall? 2
(b) (i) List three differences in structure between cell A and cell B. 3
(ii) Outline the 'pressure flow hypothesis' explanation of translocation. 6

**Total 15 marks**

2. The drawings below show parts of a plant tissue seen in longitudinal view.




(a) (i) Name the tissue to which these parts belong. 1
(ii) Name the substance used to thicken the walls and state two of its properties. 3
(iii) Which of A, B or C are found just behind apical meristems? Explain your answer. 3
(iv) Are the structures shown vessels or tracheids? Why? 2
(b) Outline the way in which water is drawn up the plant to the leaves. 6

**Total 15 marks**

3. Which of the following statements about the 'pressure flow hypothesis' are true?
**A.** The high hydrostatic pressure in a sieve tube is caused by an osmotic influx of water at the sink end.
**B.** In mass flow water flows from a region of low hydrostatic pressure to a region of high hydrostatic pressure.
**C.** Active transport is involved in pumping sucrose from source to sieve tube and from sink tube to sieve tube.
**D.** The high hydrostatic pressure in a sieve tube is caused by an osmotic influx of water at the source end.

4. Suggest reasons why:
(a) cyanide will inhibit phloem transport, 2
(b) ringing a plant will inhibit phloem transport but allow xylem transport to continue; 2
(c) The sap-seepage rate from aphid mouthparts increases the closer the aphids are to the photosynthesizing leaves. 2

**Total 6 marks**

**Answers**

1. (a) (i) phloem; 1
(ii) A = companion cell; B = sieve tube cell; C = sieve plate; 3
(iii) large plasmodesmata passing through pores;
become broken as pores are blocked with callose; 2
(b) (i) A has a large central vacuole, B has not;
A has peripheral cytoplasm, B is full of dense cytoplasm;
A has no nucleus, B has;
A has few mitochondria, B has many mitochondria; max 3
(ii) transfer cells load the sieve tube with sucrose at the source end;
this causes low water potential in the sieve tube which draws water in osmotically from the xylem;
this produces high hydrostatic pressure which pushes sap along the sieve tube/causes mass flow;
at the sink end sucrose passes to the sink thus raising the water potential in the sieve tube;
thus water leaves the sieve tube thus maintaining the hydrostatic pressure gradient from source to sink;
ref to sucrose being moved at source and sink end by active transport; 6

**Total 15 marks**

2. (a) (i) xylem; 1
(ii) lignin;
impermeable to water and dissolved solutes;
mechanically strong; 3
(iii) B and C;
ref annular thickening in C and spiral thickening in B;
these types of thickening enable elongation of the stem/protoxylem to lengthen; 3
(iv) vessels;
they have no end walls/open ended; 2
(b) ref to water drawn from xylem into mesophyll cells which have a low water potential;
caused by water loss in transpiration;
ref to cohesion of water molecules together tending to keep water column intact;
ref to adhesion of water molecules to walls of xylem vessels tending to hold water column up xylem;
ref to transpiration pull, cohesion and adhesion producing tension in the xylem water which tends to draw water up from roots to replace that which was lost from leaves;
ref to roles of atmospheric pressure/root pressure/capillarity; 6

**Total 15 marks**

3. **A.** False – water influxes at the source.
**B.** False – water flows from high to low hydrostatic pressure.
**C.** True; (sucrose will pass from sink to sieve tube when food reserves in the sink are mobilized)
**D.** True; **Total 2 marks**

4. (a) cyanide is a metabolic inhibitor which will prevent ATP production;
mass flow relies on active transport which requires energy from ATP; 2
(b) ringing removes the bark and the phloem, thus stopping phloem transport;
the xylem is to the inside of the phloem and remains intact; 2
(c) the stylets of the aphids are inserted into the sieve tubes;
the hydrostatic pressure in the sieve tubes is greatest near the source/photosynthesizing leaves, due to their high sucrose and water content; 2

**Total 6 marks**

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